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The effect of hue and saturation on apparent distance judgments.

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THE EFFECT OF HUE AND SATURATION
ON APPARENT DISTANCE
JUDGMENTS

by

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[illegible]

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ABSTRACT

This study was an attempt to determine the effects of hue and saturation (chroma) on the apparent distance of small coloured targets under two levels of absolute illumination.

Five Os participated under binocular viewing conditions. Daylight adaptation was maintained. Surface colours from the Munsell Renotation System provided eight comparison targets representing four hues (R, Y, G, B,). The four hues were matched for two saturation levels (chroma 4 and 10) and equated for luminous reflectance (value 6). A Munsell grey of the same value was used for the standard targets.

Analysis of variance clearly demonstrated significant hue and saturation effects. Yellow was judged the "nearest appearing" hue. Colours of high saturation (chroma 10) were judged to appear consistently " nearer" than those of lower saturation (chroma 4).

PREFACE.

Whether specific hues vary in their apparent distance is the question which prompted this study. An attempt is made to determine "true" hue effects by imposing controls on the saturation (chroma) and brightness (value) factors of the stimulus targets. The influence of saturation (chroma) on apparent distance judgments is a condition which merits special consideration. The effect of these factors under two levels of absolute illumination is also explored.

Dr. A.A. Smith deserves special acknowledgment for directing the development of this study. His co-operation in preparing the design, constructing the apparatus and offering many theoretical suggestions was of invaluable assistance. The author also wishes to express his appreciation to Dr. J.A. Malone C.S.B. and Rev. H.C. Hill, B.A. M.A. for their helpful suggestions. Finally, he expresses his gratitude to the subjects of his study who gave so generously of their time and especially to Stella Stelmack who typed the many drafts of this thesis so diligently.

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CHAPTER 1

INTRODUCTION

The subject of distance perception has stimulated a considerable degree of speculation and debate among theorists and experimentalists since the days of Ptolemy. It was this noted geographer and astronomer from Alexandria who began the controversy over the real and apparent size of the moon in 150 A.D. (Boring, 1957). This phenomenon, known as "the moon illusion", in which the horizon moon appears much larger than the overhead moon, has since stirred the curiosity of such men as Descartes, Lambert, Helmholtz and more recently Boring(1943). Oddly enough, it was an inquiry into this same puzzle which prompted the present study. An offchance observation by Smith[1] noted that when the moon is at the horizon, it is almost invariably a bright orange hue, in contrast to the usual white hue when it is overhead. This question was then posed: does the orange hue effectively influence the apparent increase in size (or nearness) of the moon ? From this query a more general question was derived which provided the impetus for this thesis. Does the colour of an object influence in any systematic way our judgment of its distance?

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1. Personal communication with author 1965.

An anecdote of general historical interest is related by Woodworth (1954) which demonstrates how the problem of distance perception of coloured objects was solved by Leonardo Da Vinci. The great artist was plagued by the inquiries of his pupils on how to master the depth differences of coloured objects in a landscape painting. He advised them to place a piece of glass squarely in front of them and to trace out the lines of a tree. They were instructed to move the glass slightly until the trace could be seen beside the tree and colour in the trace, matching as closely as possible the true colour of the tree. He then told them to repeat this procedure with more distant trees on the landscape. This glass, serving as a guide and teaching technique for his students, demonstrated the general rule that colours have a different appearance at varied distances.

A number of other investigators have observed that different colours, even when in the same plane seem to be at different distances and have attempted to account for this phenomenon experimentally. Among the first of these was Luckiesh (1918) who reported a brief experiment in which nine observers were asked to equate the apparent distances of a red and blue by varying the actual distance. For seven of the nine observers, the red had to be more remote if the two were to appear at the same distance. Of the remaining subjects one had to have the blue more remote, the other was inconsistent and did not show the effect at all.

In 1935, Katz found similar results when he presented a number of broad-headed nails on a board and then covered the alternate nails with red and blue papers. When viewed from a distance of 80 cm., the red papers appeared to be $\frac{1}{2}$ cm. to 1 cm. nearer than the blue. The results were reversed in reduced illumination and with a dark adapted eye. Katz concluded, or rather assumed, that the more penetrating or "insistent" the colour the nearer it appears. By the term insistent, he meant the attention catching power of a perceived colour associated especially with the saturation (richness) of chromatic colour perception and the brightness of achromatic colour perceptions.

Contrary results were obtained in an investigation conducted by Pillsbury and Schaeffer (1937). In this study, the subjects compared red from a neon light with blue from argon and neon under conditions in which the size of the light was compensated at different distances to give the same retinal image, no matter what the distance. The standard distance 295 cm. and at that distance the slit was 2.5 cm. high and 0.5 mm. wide. Under monocular conditions and with a daylight adapted eye, 11 of 15 observers judged the blue nearer than the red. In this study, the two lights were approximately equated for intensity, a factor which was apparently overlooked in the previously cited studies. Nevertheless, subjects reported that the nearer colour appeared to be brighter. The authors were unable to offer any conclusive explanation for this striking reversal from prior investigations.

It is generally accepted that brightness influences the judgment of distance. Helmholtz (1924), Ittleson (1952) and Coules (1955) demonstrates that under binocular conditions brighter objects appear nearer. With regard to colour, an investigation to determine the quantitative relationship of the actual distance of colours to the individual brightness of the respective colours was conducted by Taylor and Sumner (1945). The distances were measured at which a grey stimulus had to be placed in order that it would be judged equal in distance to each of seven coloured stimuli set at a constant distance from the subject. The method of adjustment was employed using the Howard-Dohlman apparatus fitted with Hering's coloured papers (red, yellow, blue, black and neutral grey). The viewing distance was 90 inches under restricted viewing conditions. A rank order correlation coefficient of .99 between brightness measurements of colours and their average distances from the stationary pole was obtained. A replication of this study by Johns and Sumner (1948) yielded similar results. One noteable exception was that red, although having a brightness measurement of 11.6 per cent appeared nearer than white (72 per cent) yellow (56 per cent) and green (30.5 per cent). From this evidence it is clear that in order to investigate the possibility of a true hue effect in apparent distance judgments, it is imperative to maintain the luminous reflectance or intensity constant for all hues or wavelengths.

The confounding of wavelength with the luminance in studies of the relationship between stimulus wavelength and distance judgments is a notion which Over (1962) effectively controlled in his investigations, Over confirmed his prediction that

> " when the subject was presented with two stimuli subtending the same visual angle and of the same luminance but of different wavelengths the stimulus of longer wavelength would be judged closer then the stimulus of shorter wavelength ".

The rationale upon which this prediction was based combines the fact that light from stimuli of different wavelengths stimulates different areas of the retina (chromatic abberation) with the finding that under reduced viewing conditions, two stimuli of the same wavelength are judged equal in distance when they stimulate equal areas of the retina.

In a preliminary research conducted by the introductory experimental psychology class at the University of Windsor, 1964, significant differences in the apparent distance of colour stimuli provided by Munsell papers, (red, blue, blue-green) were obtained. The papers were matched for brightness but differed in saturation because only the highest saturation (chroma) was chosen for these colours, In this case, as in the Sumner studies (1945, 1948), a Howard-Dohlman apparatus was used and the red appeared to be significantly nearer when paired with a neutral grey. At that time it was noted that the stimulus papers differed in their degree of saturation and that perhaps a saturation effect contributed to the depth error.

A number of studies (MacAdam 1950, Sanders and Wyszecki 1957,) indicate that saturated colours require less luminance (luminous reflectance) than desaturated colours in order to appear equally bright (or light). Yellow colours, because of their inherent desaturation are reported to be an exception. To illustrate this effect, a highly saturated red light, having the same luminance as a poorly saturated reddish-yellow light, generally appears to be considerably brighter than the reddish-yellow light. It seems reasonable to assume that this effect would influence apparent distance judgments in much the same way that the studies with brightness have shown. Specifically, since brighter objects appear nearer than the dimmer objects, it follows that highly saturated colours would be judged nearer than desaturated colours because the former appear to be brighter than the latter.

Supportive evidence for this thought was suggested in a study by Mount et al (1956). In this case, eight comparison stimuli consisting of four hues and their matching greys were judged for relative distance with each of two grey standard stimuli using a modified method of constant stimuli. With the standards at 200 ft. from the observer, 168 subjects made 128 judgments using one of the two grey standards. Their results clearly demonstrate that each of the hue comparison stimuli were seen in front of their nearest matching grey. The effect of hue being seen in front of the matching grey applied in the same direction for all hues and in the same general order of magnitude. However, no clear-cut differences were shown for one hue over another. The authors concluded, therefore, that the contrast favours the comparison stimulus, which was highly saturated, without regard to hue and it was seen to stand in front without exception. In effect, there were no differences that could be attributed to the introduction of specific hues. Rather, the more general conclusion was drawn that the highly saturated comparison stimuli appear nearer than their matching greys. Thus the apparent nearness of the comparison stimuli seemed to be due to a saturation effect.

The Problem of Prediction.

For the most part, the studies cited thus far have been concerned with the effect of hue, wavelength and relative brightness on apparent distance judgments. Few of the studies, however, have been sufficiently similar in design to permit a comparison of results. Marked differences in the experimental conditions also tends to impede comparisons. The scientific perspective of authors such as Over (1962) and Pillsbury and Schaeffer (1937) follows the traditional rigorous psychophysical procedure. Here, an attempt is made to eliminate every possible depth perception cue except the single independent variable which is isolated for observation. This accounts for their restricted viewing conditions i.e. a dark adapted eye, monocular vision, and constant visual angle. On the other hand, investigators such as Sumner (1945, 1948) and Mount et al. (1956) relax the conditions somewhat to approximate a normal viewing situation. In the latter case (and in the present study), information obtained from binocular viewing with daylight illumination is intended to generalize readily to practical problems.

Regardless of the motives of the investigators, whether for the cause of pure science or human engineering, the lack of consistency in results throughout these related studies poses a vexing problem. The situation makes prediction of the magnitude and the direction of the effect of hue on apparent distance judgments hazardous. But it is worthwhile to mention that the many differences noted are not due solely to the scientific sympathies of the investigators, nor is the implication of incompetence to be drawn. The chronological development of these studies reveals that there is a progression towards better control of variables previously employed and also to the addition of variables subsequently found to be relevant. In this tradition, the present study will also impose new conditions which attempt to reduce artifacts, specifically to separate a possible saturation effect from hue effect.

Choice of Stimuli.

In general, previous studies have employed either self-luminous or surface colours as stimulus objects. Surface colour is by far the most common mode of appearance. It is in this mode that most objects are perceived. For this reason, research on surface colours has an extensive field of application, including paints, lithography, commercial dyeing and even safety signs. Psychologically speaking, there is little difference between the attributes of self-luminous stimuli (illuminants) and surface (object) colours in ordinary circumstances. Illuminants tend to appear brighter than surface colours of the same intensity and wavelength (Committee on Colorimetry, 1963, p. 151). Surface colours have the additional attributes of glossiness and texture. It is in this regard that this dimension is differentiated by definition. Brightness applies to illuminants; lightness applies to surface colours.

The particular colour stimuli chosen for this study are surface colours taken from the Munsell Renotation System. In this system, all samples perceived in ordinary daylight as having the same hue are grouped together to form twenty charts. These samples serve as standards and have been selected in such a way that approximately equal saturation differences are perceived between successive members of each of these series. As a result, each group having the same hue can also be arranged in several series perceived as having approximately equal saturation(Munsell term: chroma). The standards in each such series are arranged according to lightness (Munsell term: value). The members of the grey series, and of the corresponding series of equal lightness, have been selected so that approximately equal lightness differences are perceived between successive members of each of the series of constant saturation. In short, this system can provide stimuli of different hue but equated for luminous reflectance (lightness) and saturation by using samples of the same value and chroma.

Choice of Method.

For the most part, only two psychophysical methods have been followed in studies of apparent distance judgments involving colour stimuli. The adjustment method, in which the observer is instructed to adjust a moveable comparison stimuli until it appears to be equal to a standard, was employed by Luckiesh (1918) and in the Sumner studies (1945, 1948). In both instances the Howard-Dohlman box was the main part of the apparatus. The remainder of the experimentors, Pillsbury and Schaeffer (1937), Mount et al (1956) and Over (1962) used the method of constant stimulus differences with two categories of judgment, "nearer" and " farther". In this method, fixed values of the comparison stimuli are selected to provide various fixed differences from the standard value. Each comparison stimulus is paired repeatedly with the standard stimulus, with the subject having to indicate on every trial whether the comparison stimulus is " nearer " or " farther " than the standard.

Kellogg (1929) points out the feasibility of using both methods in a comprehensive report. For the present study, the method of constant stimulus differences was adopted because the data it provides lends itself to a more versatile statistical treatment. Also, the data shows less variability between subjects and within subjects.

Statement of Problem.

The primary concern of this present study is the influence of Munsell hue and chroma (saturation) on the apparent distance of small coloured targets which are of equal Munsell value (lightness). In addition, these factors will be considered under two levels of absolute illumination to explore the possible effects of this condition. This research will undertake to investigate these variables under systematic conditions. The specific question to be considered are as follows:

1. Do specific hues, when equated for luminous reflectance (value) and saturation (chroma), vary in their apparent distances ?

2. Do more saturated colours (higher chroma) vary in their apparent distances with respect to less saturated colours (lower chroma).?

3. What influence does illumination level have on apparent distance judgments with regard to the above factors ?

CHAPTER 11

METHOD

Subjects.

The subjects were five male students between the ages of 21 and 23 attending the University of Windsor. These observers were tested prior to the experiment for normal colour vision and steropsis with the Bausch and Lomb orthorator. Each subject individually attended five two-hour sessions. Fifty hours, were required to collect the data for this study.

Apparatus.

The main part of the apparatus was constructed in the form of a rectangular box with the long axis horizontal. Four sheets of 4 ft. by 8 ft. by $\frac{3}{4}$ in. pressed wallboard were fixed to a frame of 2 in. by 4 in. beams. These were supported, front and back, by two 4 ft. by 8 ft. by $\frac{3}{4}$ in. plywood sheets mounted vertically. A 20 in. by 10 in. opening was cut in the front sheet to provide a reduction screen. A pulley-operated shutter opened and closed this aperture. The rear vertical surface was pierced by 3 holes, 1 in. in diameter, 4 in. apart from centre to centre, lying along a horizontal line. Through these holes 1 in. dowelling was passed. Black velvet material fastened to the rear surface provided a non-reflecting background. The remainder of the interior was painted a flat-white. A third vertical sheet of plywood with two viewing holes, $1\frac{1}{2}$ in. square, separated by 2 in. from centre to centre, was fitted with a viewing hood constructed from a swim mask. Mounts for 2 in. by 2 in. filters were placed in front of the viewing holes. This screen served as a viewing position for the observer. A small shelf below provided an arm-rest. The distance from the eye position to the background was 16 ft. The whole apparatus was so constructed that the centre viewing position and the centre stimulus hole lay on a horizontal line of sight, 54 in. above the floor. Schematic diagrams of the physical arrangements are presented in Figures 1 and 2.

The stimulus objects consisted of Munsell papers representing four hues, blue, green, yellow, red and a neutral grey (10B, 5G, 5Y, 5R, N,). For each hue, two saturation levels were chosen, chroma 4 and chroma 10, and all papers had a lightness value of 6. Eight hue comparison stimulus targets were employed (designated B10, R10, G10, Y10, B4, G4, R4, Y4). Specifically four hues were equated for luminous reflectance (lightness). The hues were also equated for two levels of saturation. The neutral grey paper (also of value 6) was used for the comparison target in the practice trials and for the standard stimulus targets. Colorimetic data (including Munsell renotations & C.I.E. tristimulus values) for all targets are presented in Appendix A.

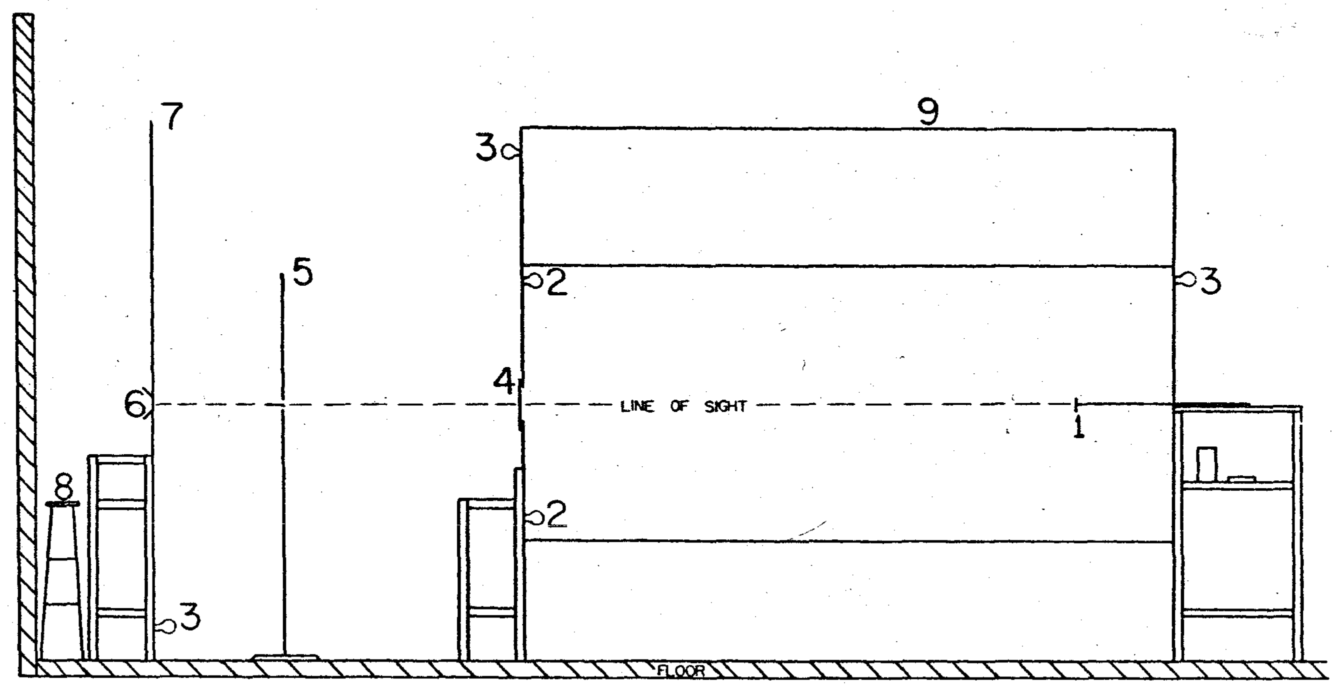

Fig. 1. Schematic diagram of apparatus, side view.

1. Stimulus target 2. interior lamps 3. exterior lamps 4. shutter
5. reduction screen 6. viewing hood 7. observer screen 8. bench 9. pulley.

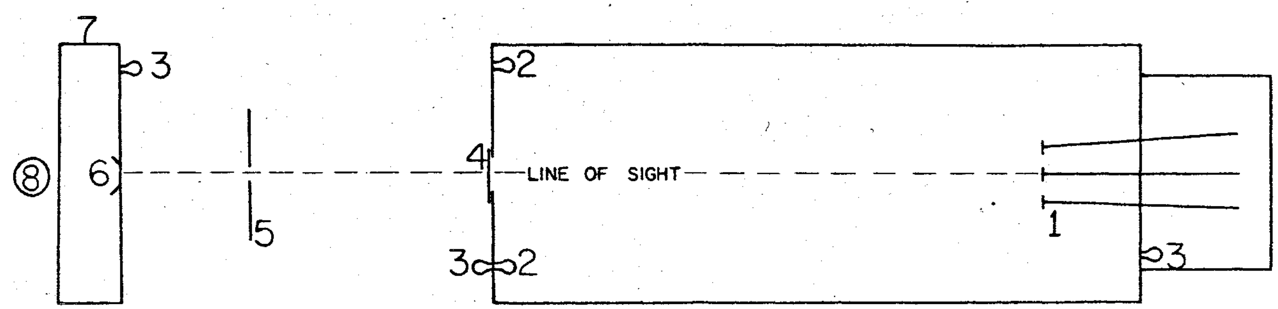

Fig. 2. Schematic diagram of apparatus, top view.

1. Stimulus targets 2. interior lamps 3. exterior lamps 4. shutter 5. reduction screen 6. viewing hood 7. observer screen 8. bench.

Stimulus targets cut from the Munsell papers and cemented to metal discs 1 in. in diameter were coupled to a thin metal rod projecting $\frac{1}{4}$ in. from the wooden dowel. The centre dowel was a moveable rod on which the comparison target was mounted. Calibrated slots in the dowel permitted accurate positioning at $\frac{1}{2}$ in. intervals in front of and behind the fixed standard targets. The grey standard targets, mounted on the two adjacent dowels, defined a reference plane at right angles to the line of sight and 18 in. in front of the background surface. The distance from the eye position to the reference plane was 14.5 ft. Two standard targets were employed instead of the usual single standard target to control the phenomenon of ocular dominance.

The interior of the box was illuminated by four lamps mounted in the four corners at the front. The lamps, 100 watt clear incandescent (G.E. 100A/1CL) give close approximation to illuminant A. (Hardy, 1936, p.16). Similar lamps were mounted externally. The power supply to the lamps was through a switch box and a Hunter timer (model 111C) so that the duration and number of exposure lamps could be accurately controlled. The interior lamps illuminated the stimulus targets for three seconds and the exterior lamps illuminated the exterior area for the inter-trial period which was approximately a five second interval. Since the Munsell colour papers are standardized in terms of illuminant C, a pair of colour temperature altering filters

(Corning glass CS 1-62), 2 in. by 2 in. square, were mounted at the viewing position. In terms of the spectral energy entering the O's eye, this arrangement was equivalent to providing average daylight conditions i.e. illuminant C.

Procedure.

In order to determine the range of stimulus positioning values to be employed in the data collecting sessions, a pre-test experiment employing the method of limits was conducted with two subjects. For each stimulus target, one ascending and one descending trial over a wide range of stimulus position values was presented to each subject. The data from this brief pre-test yielded approximate points of subjective equality (P.S.E.)[2] for each stimulus target. The three adjacent stimulus position values in front of and behind the P.S.E. approximations were selected to provide seven stimulus positions with a range of 3½ in. for each target. These stimulus position values are presented in Appendix B.

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2. For the present experiment, the P.S.E. can be defined as that physical position at which the central(moveable) target should be placed in order for it to appear, on the average, at the same distance from O as the outer (fixed) targets. In the method of constant stimuli, as employed in the present study, the P.S.E. is derived indirectly, by calculation from judgments made by O when the moveable target is at varying relative distances.

In the experiment proper, the data were collected in an almost totally dark room and the illumination was provided almost entirely from the lamps on the apparatus. In this way a constant level of adaptation was maintained. The method of constant stimulus differences was employed using two categories of judgment; "nearer or farther". The nine comparison stimuli were presented, one at a time, to the O simultaneously with the two grey standard stimuli. The specific instructions to the subjects were as follows:

> When the curtain is lifted you will see three discs on a horizontal plane. The two outside discs are at the same distance from you. Your task is to judge within a few seconds whether the disc in the centre is nearer or farther from you than the discs on the outside. You must judge nearer or farther, even if you think they are equal.

The experiment consisted of two phases. In the first phase, the stimulus targets were illuminated by two interior lamps. The grey comparison stimulus was the first target presented to each subject. This provided the practice trials. In the first trial, the centre dowel to which the target was affixed was positioned in one of the seven stimulus position calibration slots determined for the target. The shutter was raised and the illuminated target was exposed to O. At this point, O judged whether this centre target was nearer or farther from him than the two grey standard targets on either side. The judgment was recorded by E. The target was exposed to the O for three seconds. At the end of the three second exposure period, the interior lamps were extinguished and the exterior lamps were simultaneously activated to maintain daylight adaptation. Prior to testing, it was found that the three second exposure period was of sufficient duration to permit a judgment to be made and at the same time was short enough to minimize fluctuations in judgment criterion. To eliminate the cue which would have been introduced by moving the centre dowel, the shutter remained lowered during the inter-trial period while the comparison target was reset.

For the second and successive trials, the dowel to which the comparison target was affixed was set in another stimulus position calibration slot and the procedure was repeated. In all, the comparison target was presented for 15 trials at each of its seven calibration positions, giving a total of 105 consecutive presentations for this target. The order in which the target was presented at the seven stimulus position values was based on a pre-determined random arrangement.

After the practice trials with the grey comparison target were completed, one of the coloured comparison stimulus targets was selected at random and presented to O in the same manner. That is, a specific target, e.g. B10, was presented in 15 trials at the seven stimulus position values determined for B10 giving a total of 105 consecutive trials for this target. This procedure was followed for all eight hue targets. In order to eliminate a practice error which might have confounded the hue effect, the order of presentation of the eight coloured targets was also varied for each subject. The order of presentation of the comparison stimulus targets is shown in Table 1.

Table 1.

Order of Presentation of Comparison Stimulus Targets to Subjects.

Subject	Order of Presentation								
	1	2	3	4	5	6	7	8	9
1	N	G4	R4	Y4	B10	G10	R10	Y10	B4
2	N	B4	G4	R4	Y4	B10	G10	R10	Y10
3	N	R4	Y4	B10	G10	R10	Y10	B4	G4
4	N	Y4	B10	G10	R10	Y10	B4	G4	R4
5	N	B10	G10	R10	Y10	B4	G4	R4	Y4

The second phase of the experiment differed from the first phase in two respects. The illumination in the interior of the box was doubled by using four interior lamps instead of two. And, the nine comparison stimulus targets were presented in only ten trials at the seven stimulus position values, giving a total of 70 consecutive trials for each target. This reduction in the number of trials, from 105 to 70, was introduced because it was decided that the subjects were sufficiently trained from the first phase and there would not be significant reduction in the precision of the measurements. At the same time, a good deal of experimental time was conserved.

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Results.

On the basis of the "nearer" and "farther" judgments made by the O's, a point of subjective equality was calculated for each O and for each target. That is, that point was determined at which O judged the comparison stimuli to be nearer than the standard stimuli 50 per cent of the time. This was equivalent to determining the point at which O judged the comparison target equal to the standard targets. The method of average z scores as outlined by Woodworth and Schlosberg (1954, p. 205) was employed for this purpose. Both a mean (P.S.E.) and standard deviation for each comparison stimuli were obtained by this method.

As a check against the accuracy of the method, P.S.E.s were also determined graphically by plotting z scores against the stimulus position values and by the least squares method for a number of samples in this study. The results were consistent. The average z score method was chosen because unlike the graphic method which calls for fitting a line to plotted points by freehand, it is not susceptible to experimentor bias. It has the advantage over the least squares method in that it is less cumbersome and can be calculated more rapidly. Also, in order for the least squares formula to be employed successfully, the per cent nearer judgments at each stimulus position value must have some consistency. In the data provided by this study, this condition did not hold completely since there was some variability between the stimulus values, i.e. there were too many cases in which there were 100 per cent nearer or farther judgments. It is possible that this occurred because the $\frac{1}{2}$ in. stimulus position intervals were too large.

To illustrate the computation of the P.S.E., a graphic presentation for the target Y10 of one O under illumination 2 is shown in Figure 3. In this case, the per cent nearer responses at each stimulus position value have been transformed to z scores. For example, at position 0.5, O judged the target nearer eight times of the ten that it was exposed at that position. Thus, the per cent nearer response (p) is .80 and the corresponding transformation to a z score is .84. The nearer judgments at the other position values were similarly treated. In this example, although the target was presented in seven positions, only six points are plotted. The target was also presented at position 1.0, but there were 10 nearer responses (p=1.00) which represents a z score of infinity. Since "infinity" is not a determinate value, it cannot be used in standard computations. For this reason, the responses to this target position were omitted.

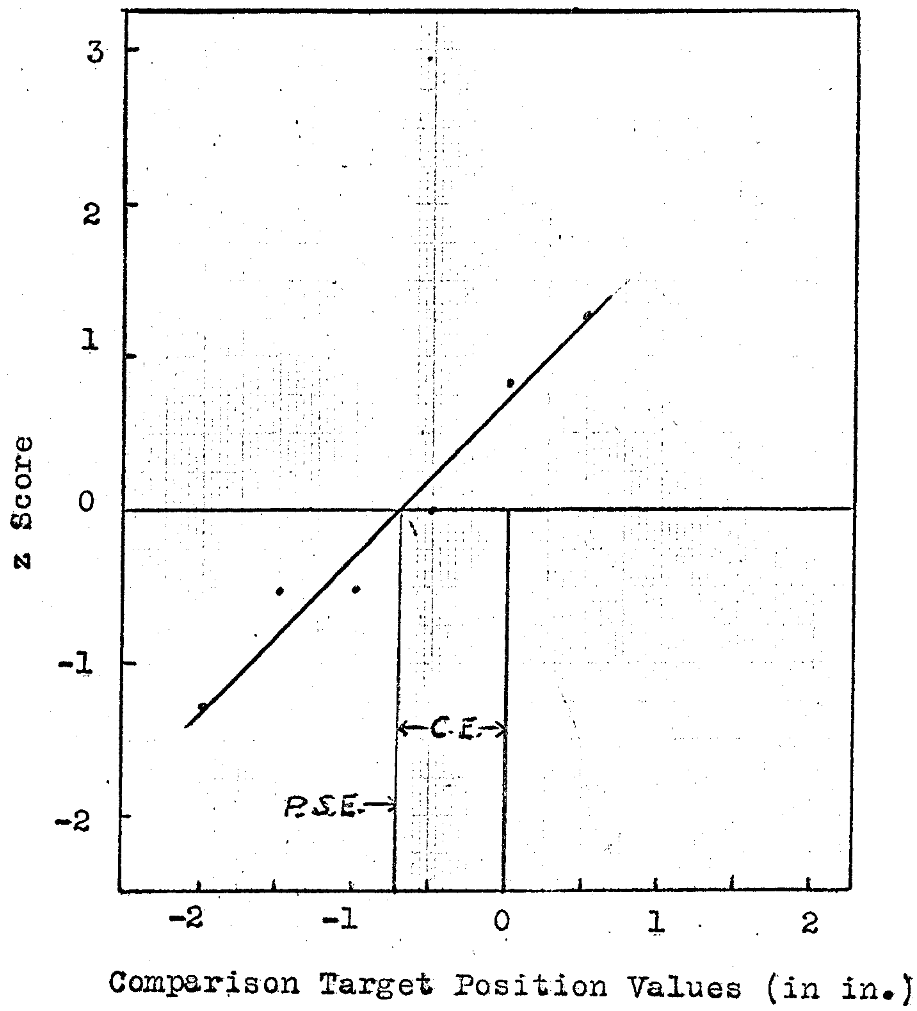

Figure 3. P.S.E. and C.E. of one comparison target.

A straight line was fitted by freehand to the plotted points. Another straight line was extended at a right angle from the ordinate where the z score is zero i.e. 50 per cent nearer responses, to intersect the data line. From that point, the P.S.E. was found by extending a straight line at a right angle to the abscissa. This point on the abscissa (in the example -.72) designated the position at which the target was judged nearer 50 per cent of the time. This graphic procedure was essentially the same method which was used to derive the P.S.E.s arithmetically. The arithmetic computation of the P.S.E. for one target is presented in Appendix C.

The difference between the standard stimuli, representing physical equality, i.e. zero position value in Figure 3, and the P.S.E. (judged equality) constitutes a constant error (C.E.) for each comparison target. In this case, the P.S.E. and C.E. have the same numerical value because the stimulus position scale has a value of zero when the comparison target is placed at physical equality with the standards.

In any case, if the P.S.E. of the comparison target was found to be behind the standards i.e. judged equal when it was actually farther from O than the standards, the C.E. was assigned a negative sign (-) to denote the direction i.e. farther. This is the case in the example in Figure 3. where C.E. is -.72 in. Thus, a target having a negative C.E. i.e. the P.S.E. was behind the standard, would have to be placed behind the standards in order to appear equal. This is tantamount to saying that the comparison targets having a negative C.E. appear to be nearer to the O than the standards, since they must be placed farther than the standards, in order to appear equal.

On the other hand, if the P.S.E. was found to be in front of the standards, the C.E. was assigned a positive sign (+) to denote this direction. Thus, if the target was assigned a positive C.E. i.e. the P.S.E. was in front of the standards, the target would have to be placed in front of the standards in order to appear equal. This is tantamount to saying that the comparison targets having a positive C.E. appear to be farther from O than the standards, since they must be placed physically nearer than the standards in order to appear equally distant. The mean C.E.s and S.D.s of the four hues with two levels of saturation (chroma 4 and chroma 10) under two levels of illumination (1 and 2) for the five Os are presented in Table 2.

Table 2.

Mean Constant Errors(in inches) and Mean Standard Deviations of 4 Hues, 2 chroma Notations(4 and 10) 2 Levels of Illumination for 5 Observers.

			Hue				
Illumin.	Chroma.		B	G	Y	R	Mean
1	4	Mean C.E.	.32	.37	.15	.29	.28
		Mean S.D.	.562	1.15	.412	.471	.649
	10	Mean C.E.	.26	.27	.06	.15	.19
		Mean S.D.	.586	.556	.421	.841	.601
		Mean C.E.	.24		Mean S.D.	.625	
2	4	Mean C.E.	.22	.16	.19	.36	.24
		Mean S.D.	.524	.447	.499	.543	.503
	10	Mean C.E.	.34	.18	-.22	.16	.12
		Mean S.D.	.526	.680	.457	.803	.616
		Mean C.E.	.18		Mean S.D.	.559	

The mean C.E.s which appear in Table 2 are plotted graphically in Figure 4. The figure illustrates the mean C.E.s of the four hues under the two levels of illumination (1 and 2) for the two chroma notations 4 and 10. The mean S.D.s in Table 2 were treated graphically in the same manner as the mean C.E.s. However, the observed relationships did not appear to merit further consideration.

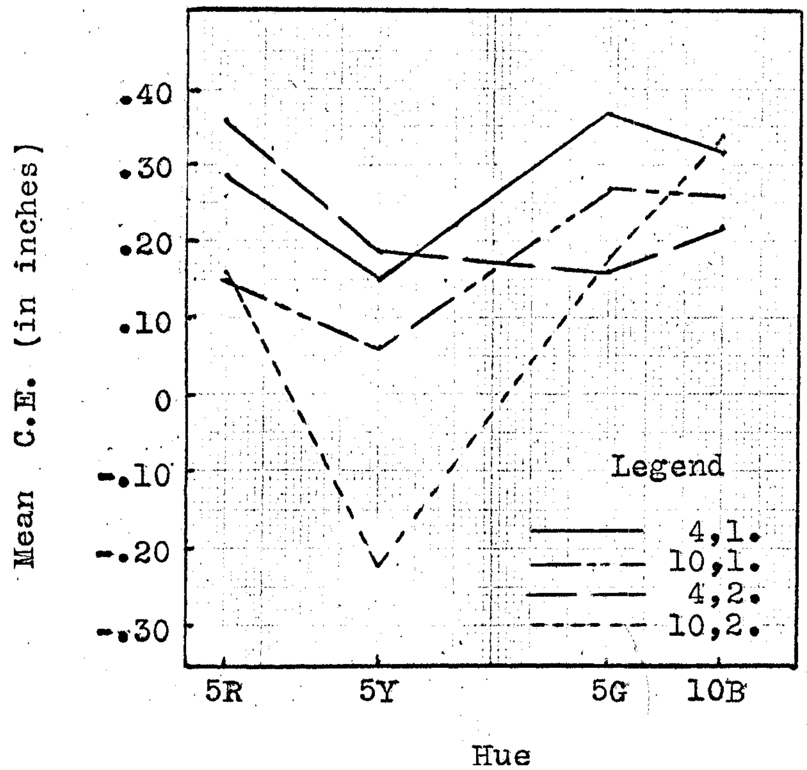

Figure 4. Mean C.E.s of Hues for chroma 4 and 10 under two levels of illumination (1 and 2). Negative(-) means target appears equal when behind standard; positive (+), target appears equal when in front of standard.

The relationships of C.E. values were treated statistically by analysis of variance to assess the degree of difference due to chance. The summary table of the analysis of variance for judged nearness by five O's for four hues, two chroma notations (saturation) and two levels of illumination is presented in Table 3. Computational data are presented in Appendix D.

Table 3.

Analysis of Variance for judged Nearness by 5 Observers for 4 Hues, 2 Chroma Notations (saturation) and 2 Levels of Illumination.

Source	df	Variance Estimate	F ratio
Between Subjects	4	1,233	2.418
Within Subjects	64	555	1.088
H (Hue)	3	2,362	4.631b
C (Chroma)	1	2,268	4.447a
I (Illumination)	1	720	1.412
HC	3	816	1.600
HI	3	413	
CI	I	15	
HCI	3	10,125	19.852c
Pooled Interactions with subjects	60	510	

(a) Significant at .05 level.
(b) Significant at .01 level.
(c) Significant at .001 level.

CHAPTER lV

DISCUSSION

The foregoing results indicate quite clearly that judgments of the relative distance of small coloured targets in approximate central fixation depend significantly on both Munsell hue and Munsell chroma. At the lower level of illumination, these effects are independent. At the higher level, however, a significant interaction occurs between hue and chroma.

Of the four hues studied, yellow shows the greatest displacement from physical equality with the grey comparison stimuli, and hence-- if the previous argument relating computed C.E.s and perceived distance is accepted-- yellow is the "nearest-appearing" colour. Also, colours of high Munsell chroma appear consistently nearer than those lower on the Munsell scale.

To what extent are these "true" hue and saturation effects ? In particular, since it has long been known (Ittleson, 1952; Coules, 1955) that brighter objects seem perceptually nearer, to what extent are the present results due solely to differential brightness-- as apparently was the case with the coloured papers used by Taylor and Sumner (1945) and Johns and Sumner (1948) ?

Judd and Wyszecki (1963 p. 222), reviewing a considerable body of evidence on the Munsell scales, claim that " all chips of the same Munsell value have closely the same luminous reflectance for standard source C". If this conclusion is valid (and there seem to be no good experimental grounds to doubt it) the different coloured targets used here were all equally bright. The counter-explanation in terms of brightness differentials can therefore be excluded with considerable confidence.

What of other alternatives ? The observation that targets of chroma 10 are consistently perceived nearer than targets of chroma 4 would argue for a genuine saturation effect, with the richer (more saturated) colours seeming nearer. Now, chroma, like value is an intensive dimension. The question here concerns the extent to which colours of the same numerical chroma are in fact equal in saturation. In effect, can it be said that chroma 10 yellow is equal in saturation to chroma 10 red ? If they are, then the present hue effect is genuine. If they are not-- and there is evidence to support this claim-- then part or all of the effects apparently due to hue differences must be attributed to differences in saturation.

On the negative side, Sempowski (1963) and Fleming (1964) basing their procedures on the argument that more highly saturated colours should require greater amounts of neutral grey to desaturate them by a known fraction, have presented evidence that equal Munsell chroma is not necessarily the same as equal saturation. However, the differences found by these investigators do not appear sufficient, either in magnitude or direction, to account for more than a small part of the present hue differences.

On the other hand, the work on the Munsell renotations (Judd and Wyszecki, 1963, p. 229) suggest that, loci of constant Munsell chroma represent equal subjective differences from achromatic grey.

Again, any simple explanation of the hue effects as due mainly to differences in saturation is in part contradicted by the present data. That is, if the differences with hue are due solely to the fact that different hues, even of the same chroma, appear to be of different saturation, then the hue and chroma effects should be additive: that is, no interaction should have been demonstrable. This seems to have been the case at the lower illumination level. However, as both the profiles (Figure 4) and the significant triple interaction between hue, chroma and illumination show, the effects were not additive at high illumination. While this effect is far from easy to explain, it does argue for the presence of genuine hue effects.

Even if Munsell chroma of constant loci do in fact represent equal subjective differences can the hue effects be accepted as valid ? If the implicit assumption is accepted that depth judgments of small coloured objects is essentially a psychological operation-- and this is the assumption when Munsell chroma are used-- then the answer seems to be affirmative. On the other hand, if there is evidence to suggest that these judgments are all or in part determined by differences in the physical qualities of hues with the same chroma, then this claim must be reconsidered.

It is well known that Munsell chroma of constant loci and equal value have different excitation purities (Judd and Wyszecki, 1963, p. 229). Excitation purity-- a strictly physical dimension-- is a ratio which designates the degree to which the dominant wavelength is present relative to a specified achromatic light. Now, what relationship, if any, is there between excitation purity and the apparent distances of the targets? The C.E.s of the targets under lower illumination show a high negative correlation ($r = -.84$) with their respective excitation purities (cf. Appendix A). That is, the higher the excitation purity ratio, the nearer the target is judged to appear. Inferences drawn from this correlation must be guarded, however, because the relative excitation purities of different hues is not strictly a linear function. Nevertheless, it is valid approximation of the true relationship. Hence, the question is raised whether or not there would be significant hue effects if the targets were matched or weighted for excitation purity as well as brightness. This problem remains to be explored.

Again, the relationship between excitation purity and apparent distance does not hold under higher illumination; the effects of this condition are still puzzling. At best, one may only speculate on a possible explanation. Some of the more plausible considerations are suggested by recent investigations of changes in hue under high levels of illumination (Roeloffs and Zeeman, 1957; Cornsweet, 1962). In general, these studies are primarily hypothetical dissertations relating changes in hue to regenerative properties of photochemical receptors in the retina.

Of particular interest to the present study is the hypothesis that increased brightness initiates a sensation of yellow (Cornsweet, 1962). If this hypothesis is valid for the present research-- and the data available are not extensive enough to be conclusive in this matter-- the striking "nearness" of yellow could possibly be accounted for on the grounds that this induced yellow sensation raises the saturation of the yellow target, and lowers the saturation of the other targets, particularly the complimentary blue target.

Excitation purity has been considered as a possible physical, as opposed to psychological, explanation of hue effects. A different physical variable has been advanced by Over (1962). As it has been pointed out, Over accounted for his findings that apparent distance was monotonically related to wavelength by invoking the well known phenomenon of chromatic aberration. In brief, the lens of the eye will focus different wavelengths at different distances (chromatic aberration). This would usually cause the retinal images of the extended targets to be of different sizes, with the image size being greater for red and decreasing monotonically as the wavelength decreases to blue. Unlike Over, the present results (cf. Figure 4) show that the relationship here is not monotonic with wavelength-- a finding which cannot be derived in any simple fashion from the facts of chromatic aberration.

Another point of theoretical interest was raised when the C.E.s of the grey comparison stimuli (practice trials) were estimated. It was assumed that since the grey target was made of the same Munsell grey paper, it would be judged very near to physical equality with the standards. However, it was found that the grey target had to be placed in front of the standards in order to appear equal. This case bears some resemblance to what is called the horopter and perhaps merits some consideration from the standpoint of methodology.

The horopter is basically "the locus of all points in space that give nondisparate images at a given degree of convergence" (Woodworth and Schlosberg, 1954 p. 460). Objects nearer or beyond these focal points but in the same line of regard give double images because they stimulate disparate points on the retina. Of interest for this study is the fact that the horopter at a focal distance of 14.5 ft. is a convex loci of points distributed horizontally on the line of normal fixation. Therefore, when the grey target is placed in front of the standards, it seems to be consistent with the curve of the horopter-- although more extensive data are required before definite conclusions can be drawn.

The curve of the horopter at different distances is usually determined by fixating on a centre stimulus target and adjusting peripheral targets until they appear as single images. Another method (Ogle, 1959) is to adjust the peripheral targets until they appear to be the same distance as the centre target. In the latter case, as in the present study, O is not required to fixate on the centre target. Another method for calculating the horopter is suggested from the data in the research. Specifically, it would involve adjusting a centre comparison target on which O fixates, to apparent equality with two stationary standards. This combines aspects of both methods and would possibly prove of interest in determining the locus of the horopter.

Some Phenomenological Observation

During the course of the experiment, several Os related that on a few occasions-- especially under high illumination-- a hazy, coloured line was imposed across the horizontal plane of the targets. The line was usually the same hue as the comparison target presented at the time. This phenomena raised the question whether or not there was a tendency for the hue of the comparison target to be induced onto the adjacent standard targets. In effect, when the blue target was presented, was there a tendency for the grey targets to appear bluish? This condition, of course, would hold for the other hues as well.

Perhaps of some esthetic interest are inquiries which were made into the colour preferences of the subjects. A low negative rank order correlation ($r = -.34$) was found between the ranked mean preferences of the targets for the five Os and their respective mean C.E.s ranked in order of apparent nearness. In effect, there was a tendency for the more "distant" appearing targets to be preferred over the "near" appearing targets.

Modifications of the Apparatus

An investigation of the functions of self-luminous stimuli in apparent distance judgments would be permitted by simple modifications in the apparatus. Self-luminous stimuli would be provided if light pipes, fitted with monochromatic light sources and appropriate filters, were substituted for the wooden dowels presently employed.

In addition, different background fields can be easily applied over the present surface to facilitate the study of contrast effects.

CHAPTER V

SUMMARY AND CONCLUSIONS

This study attempted to investigate the effects of hue and saturation (chroma) on the apparent distance of small coloured targets under two levels of absolute illumination.

Surface colours from the Munsell Renotation System provided eight comparison targets representing four hues (5R, 5Y, 5G, 10B). The four hues were matched for two saturation levels (chroma 4 and 10) and equated for luminous reflectance (value 6). A Munsell grey of the same value was used for the standard targets. In the first phase, two incandescent lamps illuminated the targets; four lamps served to double the absolute level of illumination in the second phase. In terms of the energy entering the Os eye, colour temperature altering filters inserted at the viewing position effectively provided daylight illumination (source C) from the incandescent lamps (source A).

Five Os, who were tested previously for normal colour vision and stereopsis, participated under binocular viewing conditions. Daylight adaptation was maintained. The viewing distance was 14.5 ft.

Each of the eight comparison targets was presented simultaneously with the two standard targets for a three second duration. In the first phase, each target was presented randomly at seven position settings for 105 consecutive trials. Similarly, under the higher level of illumination each target was presented for 70 consecutive trials. O was instructed to report whether the comparison target appeared nearer or farther from him than the two adjacent standard targets.

On the basis of these judgments, P.S.E.s and C.E.s were determined for each target. The C.E.s, taken to be measures of the relative nearness of each stimulus, were treated statistically by analysis of variance to determine the degree to which differences in apparent nearness were due to chance.

The results demonstrate quite clearly the presence of significant hue and saturation (chroma) effects in the apparent distance judgments of small coloured targets. At the lower level of illumination, these effects were additive. However, at the higher level, a significant interaction between hue and chroma occurred.

In general, yellow was judged the "nearest appearing" hue. Also, colours of high saturation (chroma 10) were judged consistently "nearer" than those of lower saturation (chroma 4). No conclusions were drawn from the interaction effects under high illumination, although a possible explanation was suggested. The presence of "true" hue effect was debated extensively. The principle arguments concerned the nature of the saturation scale (Munsell chroma) employed and its relationship to apparent distance judgments.

Appendix A

COLORIMETRIC DATA SHEET

For CIE Illuminant C

Book Notation	Tristimulus Values X	Tristimulus Values Y	Tristimulus Values Z	Dominant W.L.	Excitation Purity	Munsell Re-notation
10B 6/10	.2563	.2952	.7139	468	42.5	9.8B 5.95/9.6
10B 6/4	.2781	.2980	.4780	482	20.2	0.2PB 5.98/4.0
5G 6/10	.1749	.2960	.2399	511	22.0	5.2G 5.96/9.95
5G 6/4	.2415	.3031	.3009	512	9.0	5.4G 6.02/4.0
5Y 6/10	.2849	.2946	.0353	577	84.5	5.0Y 5.95/9.95
5Y 6/4	.2906	.3042	.1724	577	40.0	5.2Y 6.03/4.0
5R 6/10	.4071	.2945	.2111	610	38.0	4.7R 5.95/9.95
5R 6/4	.3361	.2982	.2960	610	14.0	4.3R 5.98/3.95
N 6/	.2979	.3047	.3550			N 6.04/

Appendix B.

Stimulus Position Values.

Target	Position from Standard (0) in inches.[3]						
N	-1.5	-1.0	-0.5	0.0[4]	0.5	1.0	1.5
B10	-1.0	-0.5	0	0.5	1.0	1.5	2.0
B4	-0.5	0	0.5	1.0	1.5	2.0	2.5
G10	-1.0	-0.5	0	0.5	1.0	1.5	2.0
G4	-0.5	0	0.5	1.0	1.5	2.0	2.5
Y10	-2.0	-1.5	-1.0	-0.5	0	0.5	1.0
Y4	-1.5	-1.0	-0.5	0	0.5	1.0	1.5
R10	-1.5	-1.0	-0.5	0	0.5	1.0	1.5
R4	-1.0	-0.5	0	0.5	1.0	1.5	2.0

3. Negative sign means that target was placed behind standard.

4. Values in this column are approximate P.S.E.s calculated from the pilot study data.

Appendix C.

Sample Computation of P.S.E.

A sample computation of the P.S.E. from the data of one subject for target Y10 under the higher level of illumination (phase 11) is presented.

Stimulus Position (in inches)	Per cent "nearer" responses	z score	
-2.0	10	-1.28	
-1.5	30	- .52	mean z for -1.5, -.773
-1.0	30	- .52	
-0.5	50	0	
0	80	.84	mean z for 0, .706
0.5	90	1.28	
1.0	100	-	

Since -1.5 is .773SD below the mean, and 0 is .706SD above the mean, the distance from -1.5 to 0, i.e., 1.5 inches equals .773 .706 1.479SD; whence SD = 1.5/1.479 = 1.014. And the mean is located .773SD above -1.5 i.e. at -.72. (P.S.E.).

Appendix D

Data (in 1/100 in.) used in computations of analysis of variance for three way classification, 2 chroma, 2 levels, of illumination, 4 hues, with 5 observers taking all conditions.

			Hue					
Illumin.	Chroma	O	B	G	R	Y	Sum	Mean
		1	52	67	25	-8	136	34
		2	45	25	40	57	167	41.75
	4	3	13	25	-12	-8	18	4.5
		4	25	43	86	18	172	43
		5	25	25	7	17	74	18.5
		Sum	160	185	146	76	567	
1		Mean	32	37	29.2	15.2		
		1	25	19	-59	-47	-62	15.5
		2	38	31	66	40	175	43.75
	10	3	16	41	2	3	62	15.5
		4	-8	16	91	59	158	39.5
		5	61	29	-27	-25	38	9.5
		Sum	132	136	73	30	371	
		Mean	26.4	27.2	14.6	6		
		1	15	5	9	59	88	22
		2	25	25	-1	-12	37	9.25
	4	3	16	2	82	17	117	29.5
		4	30	17	69	5	121	30.25
		5	25	31	20	25	101	25.25
		Sum	111	80	179	94	464	
11		Mean	22.2	16	35.8	18.8		
		1	34	58	15	-25	82	20.5
		2	44	-11	5	1	39	9.75
	10	3	39	38	52	-72	57	14.25
		4	-5	5	81	5	86	21.5
		5	59	2	-71	-20	-30	-7.5
		Sum	171	92	82	-111	234	
		Mean	34.2	18.4	16.4	-22.2		

GLOSSARY OF COLOUR TERMS

Hue: the attribute denoted by blue, green, yellow and so on.

Saturation: the attribute determining the degree of its difference from an achromatic colour perception most resembling it.

Brightness: (of an area perceived as self-luminous) the attribute permitting the colour perception to be classed as equivalent to some member of the series of achromatic colour perceptions ranging from very dim to very bright or dazzling.

Lightness: (of the colour perception of a nonself luminous object) the attribute permitting the perception to be classed as equivalent to some member of the series of achromatic object-colour perceptions ranging for light-diffusing objects from black to white.

Luminous reflectance: (of a body) ratio of reflected to incident luminous flux.

Tristimulus values: (of a colour) the amounts of three reference or matching stimuli (primary colours) required to give by additive combination a match with the light considered.

Excitation purity: the ratio of two lengths on a chromaticity diagram, the first length being the distance between the point representing the specified achromatic light and that representing the light considered, the second length being the distance along the same direction from the first point to that of the border of the chromaticity diagram.

Munsell hue: expression of one aspect of an object colour in terms of its luminous reflectance and its chromaticity coordinates. Munsell hue scales have approximately uniform perceptual steps.

Munsell value: expression of the luminous reflectance of an object colour on a scale giving approximately uniform perceptual steps under usual observing conditions.

Munsell chroma: expression of the degree of departure from the nearest achromatic colour in terms of its luminous reflectance and its chromaticity coordinates.

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